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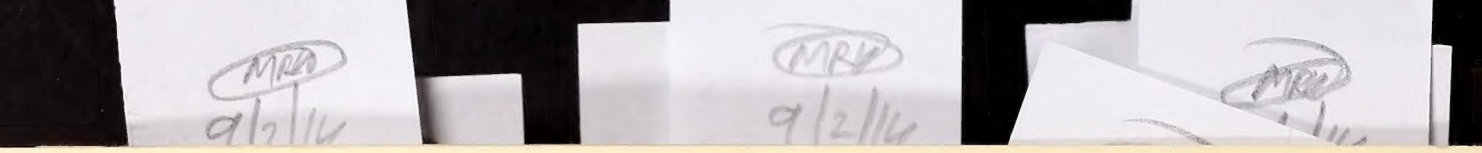
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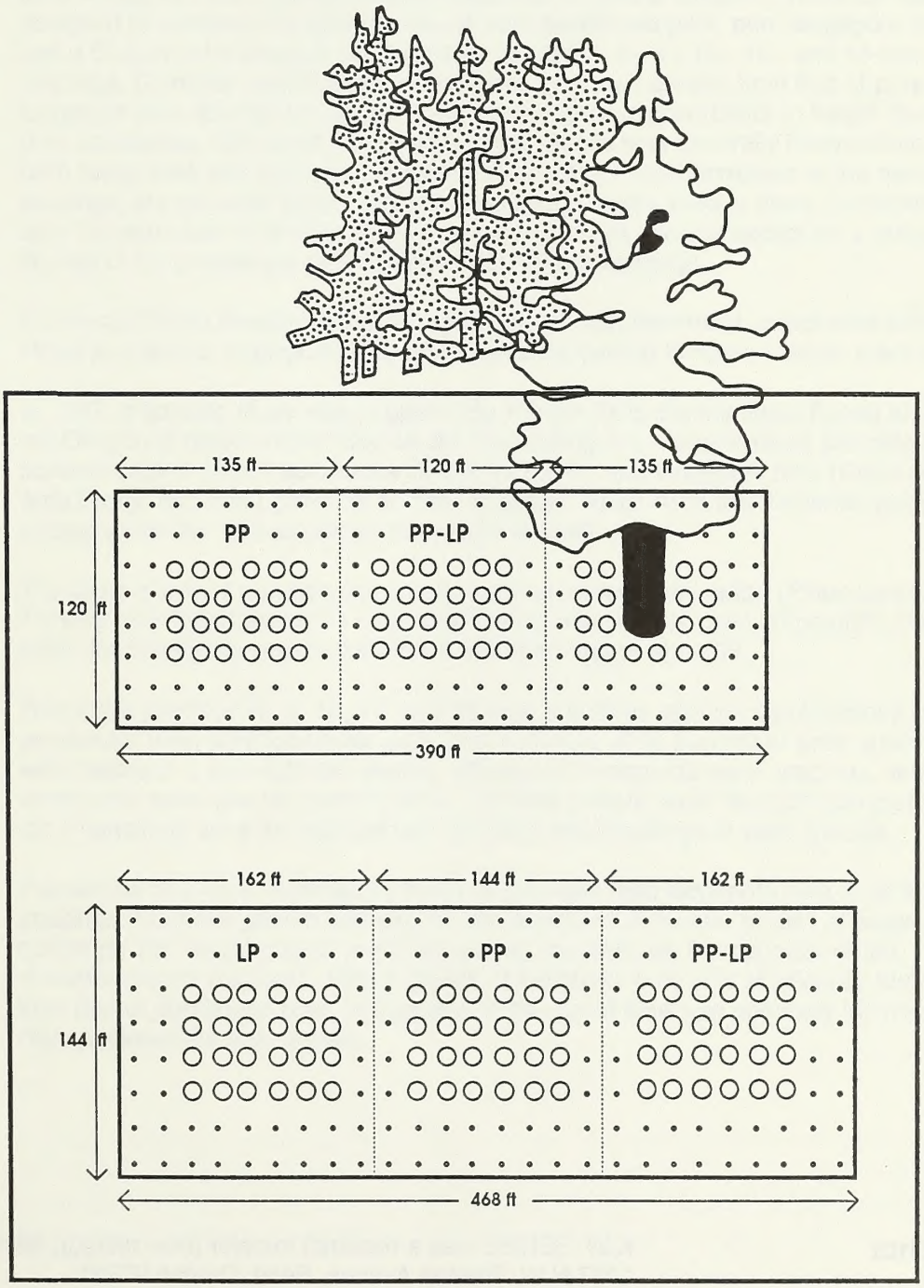
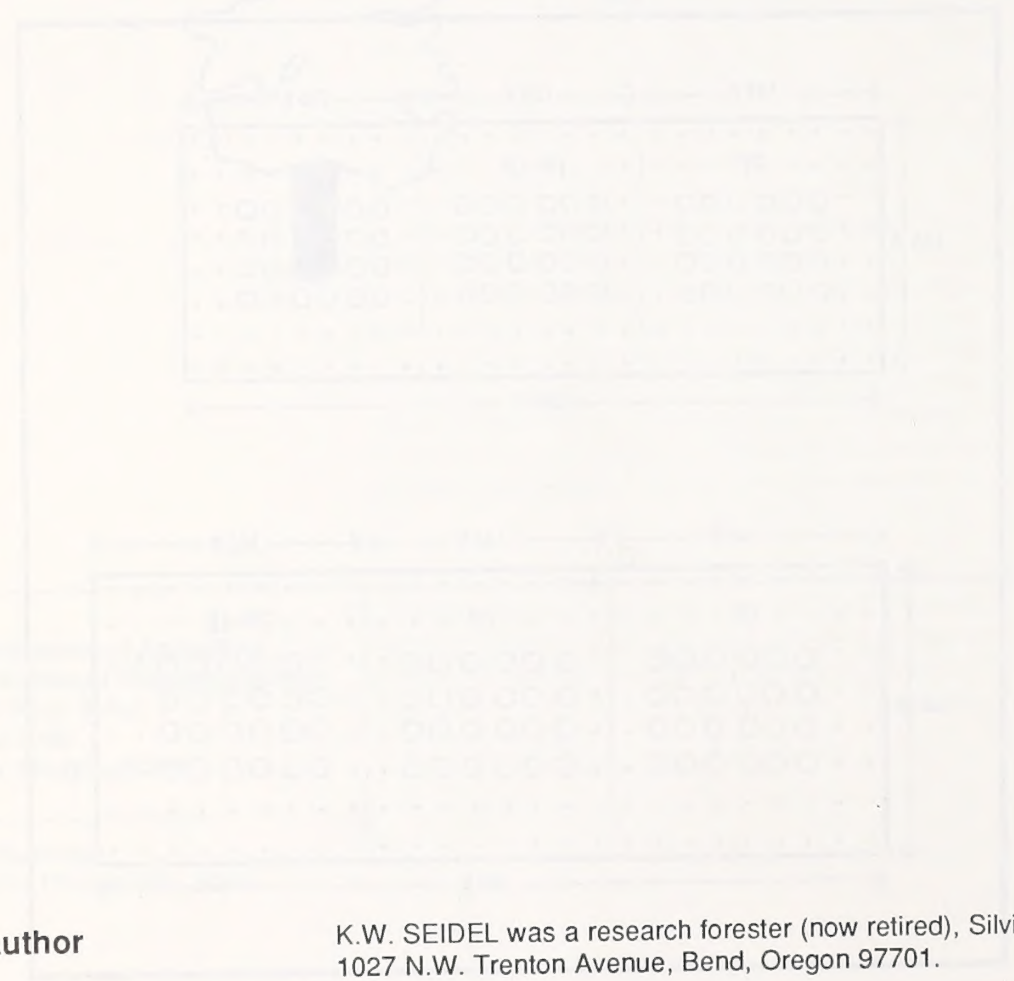
March 1989

A Ponderosa Pine-Lodgepole Pine Spacing Study in Central Oregon: Results After 20 Years

K.W. Seidel





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Abstract

Seidel, K.W. 1989. A ponderosa pine-lodgepole pine spacing study in central Oregon: results after 20 years. Res. Pap. PNW-RP-410. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 14 p.

The growth response after 20 years from an initial spacing study established in a ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) plantation was measured in central Oregon. The study was designed to compare the growth rates of pure ponderosa pine, pure lodgepole pine, and a 50-percent mixture of each species planted at 6-, 9-, 12-, 15-, and 18-foot spacings. Diameter growth of pure ponderosa pine was greater than that of pure lodgepole pine at all spacings, although pure lodgepole grew faster in height than pure ponderosa. Growth of the mixed-species stands was generally intermediate. Both basal area and total cubic volume increment per acre increased at the narrower spacings, but diameter growth per tree was less. Volume yield in these plantations after 20 years was similar for the pure pine and mixed species except for a reduction in yield of the ponderosa pine at the 6- and 12-foot spacings.

Keywords: Stand density, plantation spacing (-growth, increment, ponderosa pine, *Pinus ponderosa*, lodgepole pine, *Pinus contorta*, central Oregon, Oregon (central).

Summary

In 1967, a spacing study was begun in the Pringle Falls Experimental Forest in central Oregon to obtain information on the productivity of pure and mixed plantations of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) grown at several spacings. Responses to treatments were evaluated for the 14-year period from 1973 to 1986.

The study site is in a ponderosa pine/bitterbrush-snowbrush/sedge (*Pinus ponderosa/Purshia tridentata-Ceanothus velutinus/Carex pensylvanica*) plant community. Site index for ponderosa pine in the area is about 80 feet at age 100.

Five initial spacings (6, 9, 12, 15, and 18 feet) and three species combinations (pure ponderosa pine, pure lodgepole pine, and a mixture of 50 percent of each species) were tested in a split-split-plot design. Whole-plot treatments were spacings, split-plot treatments were species combinations, and time periods were the split-split-plot factor. Plantations were established with 2-0 bare root seedlings of both species.

Ponderosa pine grew significantly faster in diameter than lodgepole pine at all five spacings. Diameter growth followed the usual pattern of greater growth at wider spacings. The height growth response among species was the opposite of the diameter growth response: Height growth of lodgepole pine was signficantly faster than that of ponderosa pine, and growth of the mixed pine was generally intermediate between the pure stands.

Basal area growth was significantly related to spacing and showed the typical pattern of greater growth at closest spacings. Growth rates among species did not differ significantly when averaged over all spacings and time periods. Gross annual volume growth was significantly related to spacing in the same way as was basal area growth—greatest growth at narrow spacings and decreasing as spacing became wider. Pure lodgepole pine had the greatest annual volume growth (32 cubic feet per acre), pure ponderosa pine had the least (27 cubic feet), and growth of the mixed species was intermediate (31 cubic feet).

Twenty years after planting, the net volume yield of pure ponderosa pine and pure lodgepole pine at the five spacings reflect the pattern of growth during this time—less wood produced by ponderosa pine at the 6-, 9-, and 12-foot spacings and more wood produced at the 15- and 18-foot spacings when compared to lodgepole pine.

Spacing studies provide information on tradeoffs between diameter growth rates and volume yields at various stand densities. Stand density must be controlled to attain diameter growth rates sufficient to reach target diameters in the desired timeframe. Because maximum volume yield occurs at high stand densities and maximum diameter growth occurs at low densities, some yield is generally sacrificed to produce larger trees in an acceptable time. Ponderosa pine and lodgepole pine plantations should be managed so that stand density does not reach levels that cause reduced tree vigor and predispose the stand to attacks from the mountain pine beetle (*Dendroctonus ponderosae*).

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Introduction

Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws) is commonly planted on many areas in pine and mixed-conifer communities in central Oregon after timber harvesting is completed. Lodgepole pine (*Pinus contorta* Dougl. ex Loud.) is also planted in units where freezing temperatures are a problem because of its greater frost resistance (Cochran and Berntsen 1973). When the two species are planted together, forest managers need information on the growth and yield response of such mixed-species plantations to select tree spacing or to design thinning schedules meeting land management objectives. This information is also valuable to develop and verify long-term growth and yield models of managed stands.

In 1967, a spacing study was begun in central Oregon in a plantation established with seedlings of ponderosa pine and lodgepole pine. The purpose was to obtain information on the productivity of pure and mixed stands of these species at several spacings through data on diameter, height, basal area, volume growth, and mortality. This paper reports results from 14 years, consisting of two 5-year growth periods and one 4-year period (1973-77, 1978-81, and 1982-86). Results are directly applicable only to plantations in the plant community where the study is located but should be generally useful in similar pine communities of comparable site quality on the east slopes of the Cascade Range from Bend to Klamath Falls.

Study Area and Methods

The study site is in the Pringle Falls Experimental Forest in the Deschutes National Forest near Bend, on a west-facing, 15-percent slope at an elevation of about 4,600 feet. The soil is well-drained Typic Cryorthent (Shukash series) that developed in dacite pumice originating from the eruption of Mount Mazama about 6,500 years ago. It has an A1, AC, C1, C2 pumice horizon that is about 3 feet deep over the buried soil.

The study area is a 12-acre clearcutting in a ponderosa pine/bitterbrush-snowbrush/sedge plant community (Volland 1985). Typical ground cover in this community consists primarily of bitterbrush (*Purshia tridentata* (Pursh) DC.), snowbrush (*Ceanothus velutinus* Dougl. ex Hook.), and long-stolon sedge (*Carex pensylvanica* Lam.). Site index of mature ponderosa pine in the area is about 80 feet at age 100 (Meyer 1961).

Five initial spacings (6, 9, 12, 15, and 18 feet) and three species combinations (pure ponderosa pine, pure lodgepole pine, and a mixture of 50 percent of each species) were tested in a completely randomized split-split-plot design. Whole-plot treatments were spacings, split-plot treatments were species combinations, and time periods were the split-split plot factor. Each spacing was replicated two times for a total of 10 whole plots; each whole plot was split into 3 subplots resulting in 30 subplots (fig. 1). The 50-percent mixed-pine subplots were planted by alternating species within each row. Twenty-four trees were measured in the interior of each subplot; size of subplots, including buffer strips, ranged from 0.1 to 0.54 acre, depending on spacing. No future thinning is planned for these plots.

Planted seedlings of both species were 2-0 bare root stock grown in the USDA Forest Service nursery in Bend. Seedlings were planted with an auger in spring 1967. Snowbrush within the study area was sprayed with herbicide twice in the first 5 years after planting to reduce competition from this species.

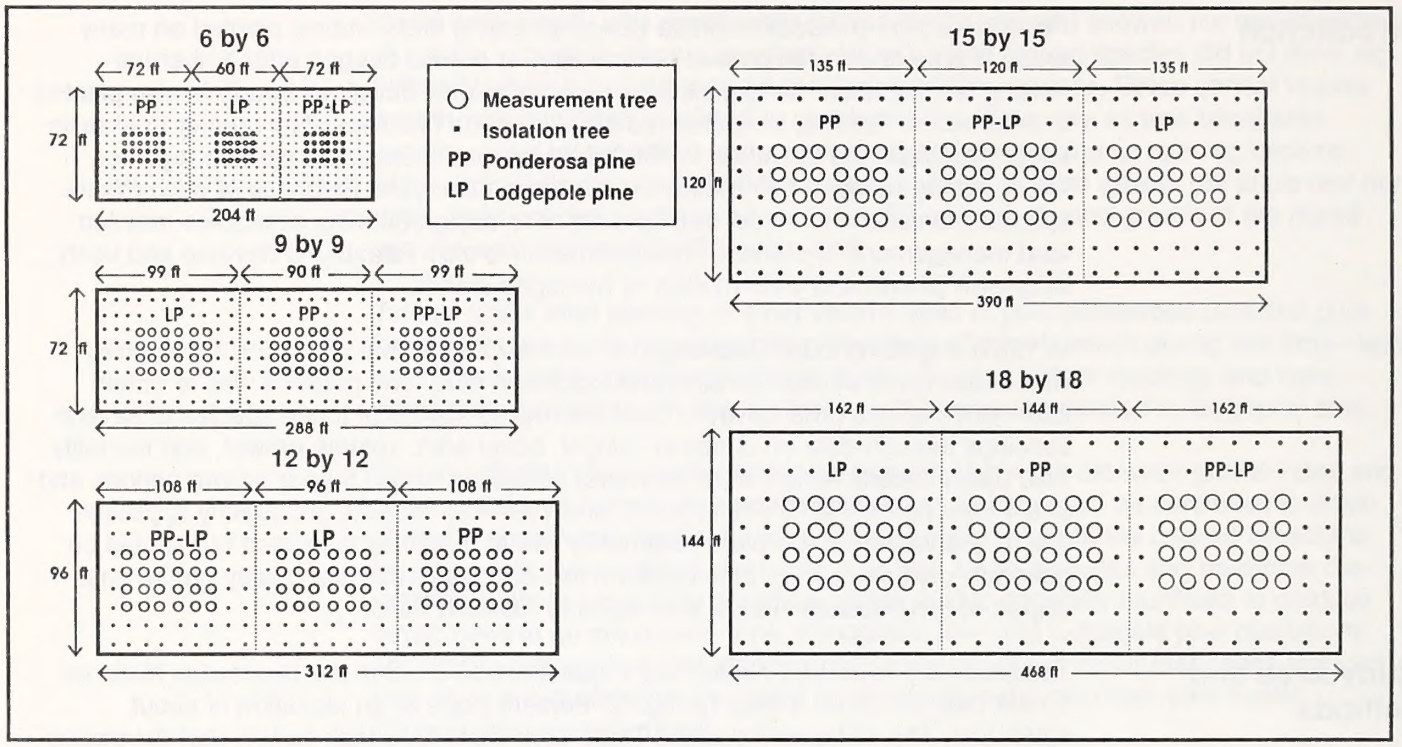

Figure 1—One replication of spacing plots showing random assignment of the species combination split plots within each whole plot.

Total height of all plot trees was measured to the nearest 0.1 foot in spring 1973, 1978, and 1982 and in fall 1986. Diameter at breast height (d.b.h.) of trees 0.6 inch or larger was measured to the nearest 0.1 inch in 1978, 1982, and 1986. An equation expressing total cubic volume inside bark as a function of diameter^2 × height (D^2H) was constructed for each species and used for volume estimation in 1978, 1982, and 1986.

Split-plot analyses of variance were used to compare spacings, species mix, and growth periods for diameter, height, basal area, and volume growth. Tukey's test was used to determine significant differences among treatment means.

Characteristics of the plots in 1973 (age 6), in 1978 (age 11), in 1982 (age 15), and in 1986 (age 20) are given in table 1. Tree ages in this paper do not include the 2 years in the nursery and thus are years since planting.

Table 1—Characteristics of ponderosa pine-lodgepole pine plots and subplots in 1973, 1978, 1982, and 1986

Spacing and species composition	Trees per acre	Trees per acre 0.6-inch d.b.h. or larger		Quadratic mean diameter[a]	Average height[b]	Basal area[a]	Total volume[a]
			Percent	*Inches*	*Feet*	*Square feet per acre*	*Cubic feet per acre*
				1973 (Age 6)			
6 by 6 feet:							
Ponderosa	1,200	0	0	—	1.7	—	—
Lodgepole	1,200	0	0	—	2.7	—	—
Ponderosa-lodgepole	1,200	0	0	—	2.5	—	—
Mean	1,200	0	0	—	2.3	—	—
9 by 9 feet:							
Ponderosa	538	0	0	—	1.9	—	—
Lodgepole	538	0	0	—	2.3	—	—
Ponderosa-lodgepole	538	0	0	—	2.4	—	—
Mean	538	0	0	—	2.3	—	—
12 by 12 feet:							
Ponderosa	303	0	0	—	1.4	—	—
Lodgepole	303	0	0	—	2.2	—	—
Ponderosa-lodgepole	303	0	0	—	1.8	—	—
Mean	303	0	0	—	1.8	—	—
15 by 15 feet							
Ponderosa	194	0	0	—	1.6	—	—
Lodgepole	194	0	0	—	1.9	—	—
Ponderosa-lodgepole	194	0	0	—	2.3	—	—
Mean	194	0	0	—	1.9	—	—
18 by 18 feet							
Ponderosa	134	0	0	—	2.2	—	—
Lodgepole	134	0	0	—	2.4	—	—
Ponderosa-lodgepole	134	0	0	—	2.1	—	—
Mean	134	0	0	—	2.2	—	—
				1978 (Age 11)			
6 by 6 feet							
Ponderosa	1200	775	65	1.3	5.3	6.6	128.3
Lodgepole	1200	1150	96	1.5	8.5	13.8	196.3
Ponderosa-lodgepole	1200	925	77	1.7	7.7	15.0	182.3
Mean	1200	950	79	1.5	7.2	11.8	169.0
9 by 9 feet							
Ponderosa	538	382	71	1.7	6.6	5.8	74.9
Lodgepole	538	471	88	1.9	9.2	8.7	100.3
Ponderosa-lodgepole	538	516	96	1.7	8.4	7.9	97.7
Mean	538	456	85	1.8	8.1	7.5	91.0
12 by 12 feet							
Ponderosa	303	139	46	1.5	4.8	1.8	25.6
Lodgepole	303	265	87	1.6	8.3	3.5	47.5
Ponderosa-lodgepole	303	227	75	1.4	6.7	2.4	38.0
Mean	303	210	69	1.5	6.6	2.6	37.0

Table 1—Characteristics of ponderosa pine-lodgepole pine plots and subplots in 1973, 1978, 1982, and 1986 (continued)

Spacing and species composition	Trees per acre	Trees per acre 0.6-inch d.b.h. or larger		Quadratic mean diameter[a]	Average height[b]	Basal area[a]	Total volume[a]
			Percent	*Inches*	*Feet*	*Square feet per acre*	*Cubic feet per acre*
15 by 15 feet							
Ponderosa	194	132	68	1.7	5.9	2.0	25.8
Lodgepole	194	163	84	1.6	7.4	2.1	27.4
Ponderosa-lodgepole	194	151	78	2.0	7.5	3.3	34.1
Mean	194	149	77	1.8	6.9	2.5	29.1
18 by 18 feet:							
Ponderosa	134	110	82	2.0	7.1	2.5	25.4
Lodgepole	134	116	87	1.9	8.6	2.3	24.2
Ponderosa-lodgepole	134	105	78	1.9	7.3	1.9	21.2
Mean	134	110	82	1.9	7.7	2.2	23.6
				1982 (Age 15)			
6 by 6 feet							
Ponderosa	975	900	92	2.4	9.2	26.9	251.8
Lodgepole	1200	1175	98	2.5	13.0	39.3	390.3
Ponderosa-lodgepole	1150	1075	93	2.6	12.0	39.7	381.5
Mean	1108	1050	94	2.5	11.4	35.3	341.2
9 by 9 feet							
Ponderosa	538	516	96	3.0	10.8	24.6	208.2
Lodgepole	538	516	96	3.2	14.3	27.4	251.8
Ponderosa-lodgepole	538	527	98	3.2	12.4	29.2	246.3
Mean	538	520	97	3.1	12.5	27.1	235.4
12 by 12 feet							
Ponderosa	297	259	87	2.6	8.8	9.5	83.1
Lodgepole	303	303	100	3.1	14.4	15.6	144.7
Ponderosa-lodgepole	303	271	89	2.9	11.4	12.4	108.8
Mean	302	278	92	2.9	11.5	12.5	112.2
15 by 15 feet							
Ponderosa	186	167	90	3.7	11.8	12.4	98.4
Lodgepole	194	186	96	3.3	13.7	11.2	95.0
Ponderosa-lodgepole	175	167	95	3.9	13.9	13.6	114.0
Mean	185	173	94	3.6	13.1	12.4	102.5
18 by 18 feet							
Ponderosa	132	127	96	4.0	12.5	10.9	86.0
Lodgepole	132	129	98	3.6	14.5	9.3	82.5
Ponderosa-lodgepole	129	124	96	3.7	13.7	9.5	79.7
Mean	131	127	97	3.8	13.6	9.9	82.7
				1986 (Age 20)			
6 by 6 feet							
Ponderosa	875	850	97	3.7	13.9	62.3	530.5
Lodgepole	1200	1200	100	3.4	18.9	73.8	796.8
Ponderosa-lodgepole	1050	1025	98	3.5	17.5	70.2	713.8
Mean	1042	1025	98	3.5	16.8	68.8	680.4

Table 1—Characteristics of ponderosa pine-lodgepole pine plots and subplots in 1973, 1978, 1982, and 1986 (continued)

Spacing and species composition	Trees per acre	Trees per acre 0.6-inch d.b.h. or larger		Quadratic mean diameter[a]	Average height[b]	Basal area[a]	Total volume[a]
			Percent	*Inches*	*Feet*	*Square feet per acre*	*Cubic feet per acre*
9 by 9 feet							
Ponderosa	527	527	100	4.5	16.2	57.9	522.7
Lodgepole	538	538	100	4.4	20.2	55.5	575.2
Ponderosa-lodgepole	516	516	100	4.7	19.7	61.0	595.1
Mean	527	527	100	4.5	18.7	58.1	564.3
12 by 12 feet							
Ponderosa	278	252	91	4.5	13.7	26.8	226.6
Lodgepole	303	303	100	4.7	21.1	36.4	387.1
Ponderosa-lodgepole	290	278	96	4.5	17.0	30.8	295.1
Mean	290	278	96	4.6	17.3	31.3	302.9
15 by 15 feet							
Ponderosa	186	182	98	6.0	19.0	34.9	340.9
Lodgepole	190	190	100	5.3	20.8	29.3	295.8
Ponderosa-lodgepole	171	171	100	6.0	21.1	33.1	325.9
Mean	182	181	99	5.8	20.3	32.4	320.9
18 by 18 feet							
Ponderosa	132	132	100	6.4	19.5	28.8	277.8
Lodgepole	126	126	100	5.6	22.1	21.7	231.8
Ponderosa-lodgepole	129	129	100	6.0	20.8	25.1	254.7
Mean	129	129	100	6.0	20.8	25.2	254.8

[a] All trees 0.6-inch d.b.h. and larger.
[b] All trees.

Results and Discussion

Diameter Growth

Ponderosa pine grew significantly faster ($P<0.01$) in diameter than lodgepole pine at all five spacings during the second and third periods (table 2). The most rapid rate of diameter growth (0.61 inch per year) occurred on ponderosa pine at the 15-foot spacing during the second period; the slowest growth rate (0.18 inch per year) was measured on lodgepole pine at the 6-foot spacing during the third period. Diameter growth increased as spacing became wider for both pure and mixed species during both growth periods, except for growth in pure stands at the 18-foot spacing, which was equal to or slightly less than growth at the 15-foot spacing. This slowing of growth at the 18-foot spacing was not expected because previous work shows a steady increase of diameter growth of ponderosa pine saplings up to a 26-foot spacing (Barrett 1982).

Diameter growth slowed significantly ($P<0.01$) from the second to the third period at all spacings and for both pure and mixed stands. This is a common response in many spacing studies and is probably the result of increasing age and stand density.

Table 2—Periodic annual diameter and height increment of ponderosa pine, lodgepole pine, and mixed ponderosa pine-lodgepole pine plots during three measurement periods from 1973 to 1986

Age and spacing	Diameter growth[a]				Height growth[b]			
	Ponderosa	Lodgepole	Ponderosa-lodgepole	Mean	Ponderosa	Lodgepole	Ponderosa-lodgepole	Mean
	Inches[c]				*Feet*[c]			
				1973-77				
Age 6-11 years:								
6 by 6 feet	—	—	—	—	0.8 ± 0.05	1.2 ± 0.05	1.1 ± 0.15	1.0 ± 0.12
9 by 9 feet	—	—	—	—	1.0 ± .05	1.4 ± .05	1.2 ± 0	1.2 ± .12
12 by 12 feet	—	—	—	—	.7 ± .05	1.2 ± 0	1.0 ± 0	1.0 ± .15
15 by 15 feet	—	—	—	—	.9 ± 0	1.1 ± 0	1.1 ± .05	1.0 ± .07
18 by 18 feet	—	—	—	—	1.0 ± .05	1.2 ± .10	1.1 ± .05	1.1 ± .06
				1978-81				
Age 12-15 years:								
6 by 6 feet	0.35 ± 0.05	0.26 ± 0.03	0.27 ± 0.01	0.29 ± 0.03	.9 ± .20	1.2 ± .15	1.0 ± .10	1.0 ± .09
9 by 9 feet	.42 ± .01	.36 ± .03	.39 ± .01	.39 ± .02	1.1 ± .05	1.3 ± .05	1.2 ± 0	1.2 ± .06
12 by 12 feet	.45 ± .02	.43 ± .06	.43 ± .06	.44 ± .01	1.0 ± .10	1.5 ± .10	1.2 ± .10	1.2 ± .15
15 by 15 feet	.61 ± .03	.49 ± .01	.53 ± .01	.54 ± .04	1.5 ± .05	1.6 ± .10	1.5 ± .10	1.5 ± .03
18 by 18 feet	.56 ± .04	.49 ± .03	.57 ± .01	.54 ± .03	1.4 ± .05	1.5 ± .10	1.6 ± .05	1.5 ± .06
				1982-86				
Age 16-20 years:								
6 by 6 feet	.27 ± .01	.18 ± 0	.19 ± .02	.21 ± .03	.9 ± 0	1.2 ± 0	1.1 ± .15	1.1 ± .09
9 by 9 feet	.32 ± .01	.27 ± .01	.29 ± .01	.29 ± .01	1.1 ± .05	1.2 ± .10	1.3 ± .05	1.2 ± .06
12 by 12 feet	.40 ± .08	.33 ± .03	.36 ± .04	.36 ± .02	1.0 ± .20	1.4 ± .05	1.2 ± .05	1.2 ± .12
15 by 15 feet	.51 ± .02	.42 ± 0	.46 ± .01	.46 ± .03	1.4 ± 0	1.4 ± 0	1.5 ± .05	1.4 ± .03
18 by 18 feet	.51 ± .04	.40 ± .01	.48 ± .01	.46 ± .03	1.4 ± .10	1.5 ± .05	1.4 ± 0	1.4 ± .03

[a] Arithmetic mean diameter growth of trees 0.6 inch d.b.h. or larger at beginning of each period and living through the period.
[b] Based on growth of all trees living through each period.
[c] Mean ± standard error.

Because of the more rapid diameter growth of ponderosa pine, average stand diameter 20 years after planting was greater for it than for lodgepole pine at all spacings except the 12-foot spacing (fig. 2). The greatest differences were at the 15- and 18-foot spacings where average diameter of ponderosa pine was 14 percent larger (0.7-0.8 inch) than that of lodgepole pine. Average diameter of ponderosa pine growing at the 12-foot spacing was less than for ponderosa pine at the 9-foot spacing at age 11 and 15; but at age 20, average stand diameters were the same at both spacings because of the accelerated growth at the 12-foot spacing during the third period. This suggests that the expected pattern of increasing stand diameter from narrow to wide spacing will be found in the future for ponderosa pine as now exists for lodgepole pine.

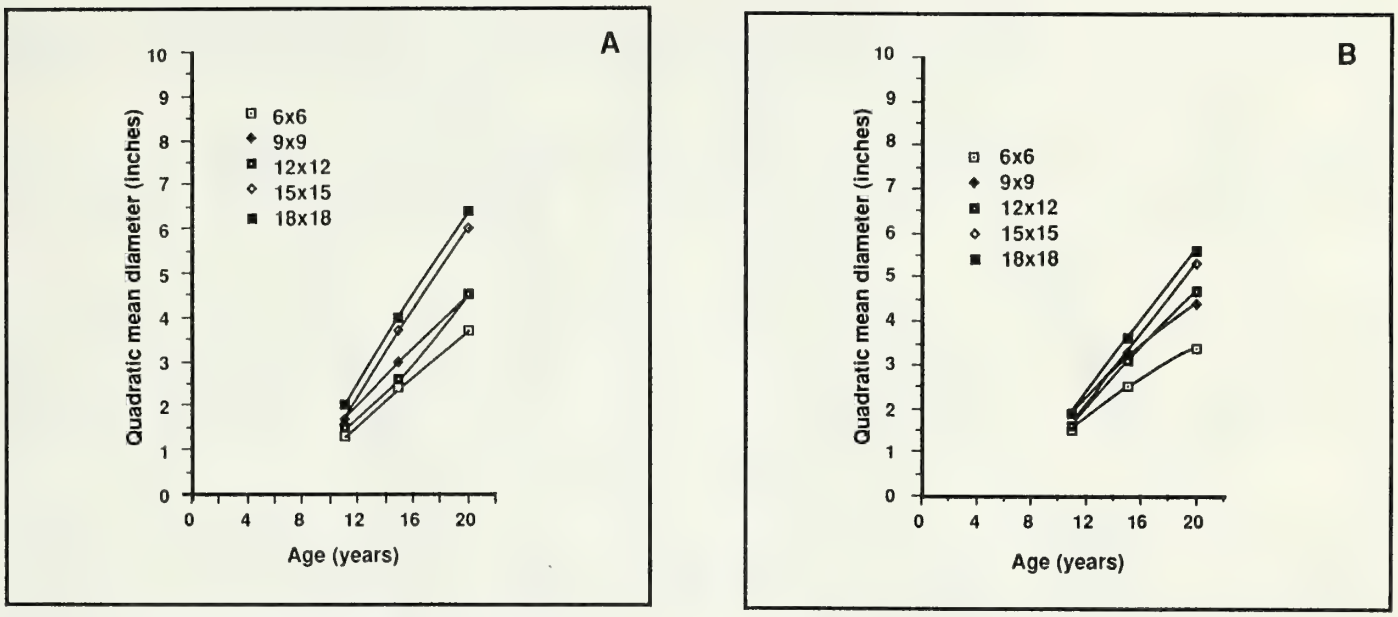

Figure 2—Quadratic mean diameter of trees growing at five initial spacings from age 11 to 20: **(A)** ponderosa pine and **(B)** lodgepole pine.

Height Growth

Lodgepole pine grew significantly faster ($P<0.01$) in height than ponderosa pine during all three growth periods (table 2). Growth of the mixed pine was generally intermediate between the pure stands. Average height growth ranged from 0.7 foot per year for pure ponderosa pine at the 12-foot spacing during the first period to 1.6 feet per year for pure lodgepole pine at the 15-foot spacing during the second period. These growth rates are typical of pine responses in other studies in central Oregon (Barrett 1982, Dahms 1971, Seidel 1985).

Spacing had a significant effect ($P<0.05$) on height growth but only between the 6- and 15-foot spacings and the 6- and 18-foot spacings. Height growth generally increased as spacing increased, but this trend was not as consistent or uniform as the one for diameter growth.

Height growth during the first period was significantly less ($P<0.01$) than during the second or third periods, but no significant growth difference occurred between the second and third periods.

Because of the faster height growth of lodgepole pine, this species was significantly taller ($P<0.01$) than ponderosa pine at all spacings after 20 years (fig. 3). Differences in average height between the two species ranged from a 1.8-foot advantage (9 percent) for lodgepole pine at the 15-foot spacing to a 7.4-foot advantage (35 percent) at the 12-foot spacing.

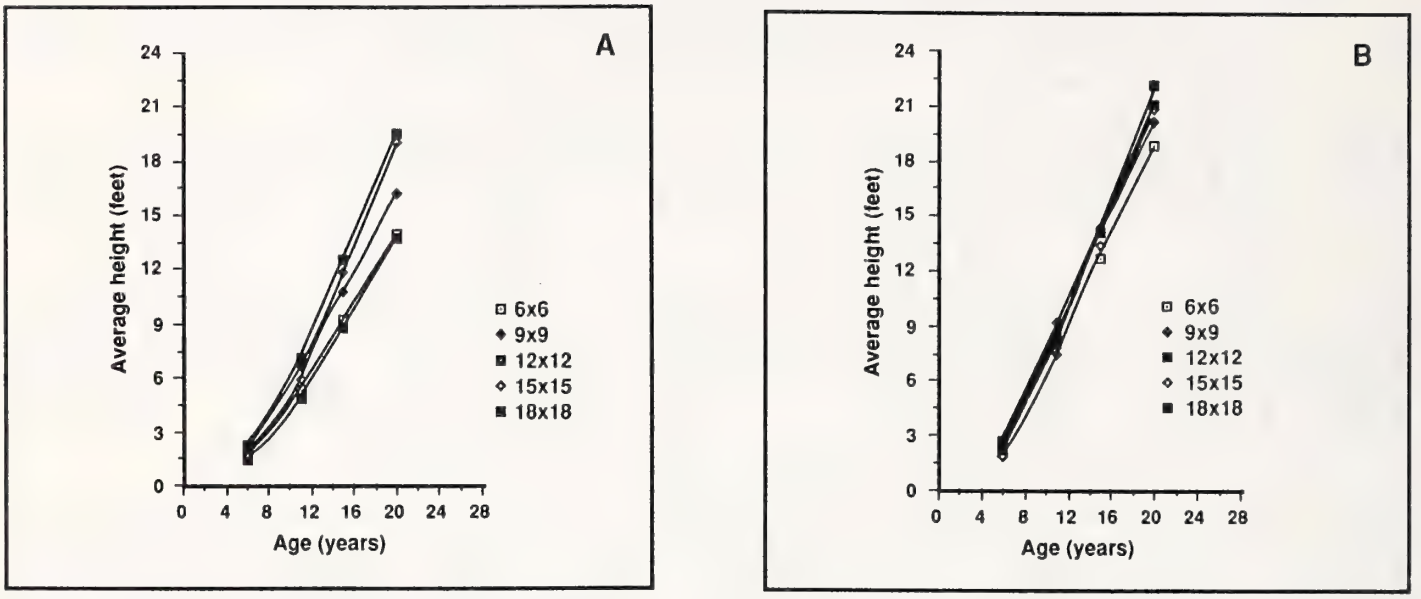

Figure 3—Average height of trees growing at five initial spacings from age 6 to 20: **(A)** ponderosa pine and **(B)** lodgepole pine.

Mortality

Mortality was greatest for ponderosa pine at the 6-foot spacing during the second period where 225 trees per acre or 19 percent of the trees were lost (table 3). Ponderosa mortality declined with wider spacing; only two trees per acre died (1.5 percent) at the 18-foot spacing during the second period and none during the third. Lodgepole pine mortality was negligible in the pure plots, amounting to only two to six trees per acre. In the mixed pine plots, about 40 percent of the mortality was lodgepole pine. During the entire 20 years, 6 percent of the study trees died; three-quarters of these were ponderosa pine and one-quarter were lodgepole pine.

Because most of the trees that died were in the 1- and 2-inch diameter classes, the effect on gross basal area or volume increment was small (table 3). The greatest impact was at the 6-foot spacing, where mortality reduced gross volume growth by about 5 cubic feet per acre per year in the pure ponderosa and mixed-pine plots. Most of the mortality was apparently caused by the root rot *Armillaria* sp.

Basal Area Growth

Basal area growth was significantly ($P<0.01$) related to spacing and showed the typical pattern of greater growth at closest spacings with a steady decline as spacing became wider (table 4). Gross periodic annual increment ranged from a high of 7.4 square feet per acre during the third period at the 6-foot spacing to a low of 0.4 square foot at the 12-foot spacing during the first period on ponderosa pine. Basal area growth increased significantly ($P<0.01$) from period to period. Averaged over all spacings and species combinations, annual growth was 1.1, 3.5, and 4.7 square feet per acre for the first through third periods, respectively. Growth rates among species did not differ significantly; the average was 3.0, 3.1, and 3.2 square feet per acre for pure ponderosa, pure lodgepole, and mixed species, respectively, over all spacings and periods.

Table 3—Periodic annual mortality of ponderosa pine, lodgepole pine, and mixed ponderosa pine-lodgepole pine plots during the second and third measurement periods from 1973 to 1986[a]

Age and spacing	Trees			Basal area			Volume		
	Ponderosa	Lodgepole	Ponderosa-lodgepole	Ponderosa	Lodgepole	Ponderosa-lodgepole	Ponderosa	Lodgepole	Ponderosa-lodgepole
	Number per acre			*Square feet per acre*			*Cubic feet per acre*		
				1978-81					
Age 12-15 years:									
6 by 6 feet	225	—	50	0.24	—	—	5.0	—	—
9 by 9 feet	—	—	—	—	—	—	—	—	—
12 by 12 feet	16	—	—	—	—	—	—	—	—
15 by 15 feet	18	—	19	—	—	0.01	—	—	0.13
18 by 18 feet	2	2	5	—	0.01	—	—	0.13	—
				1982-86					
Age 16-20 years:									
6 by 6 feet	100	—	100	.30	—	.50	3.3	—	5.3
9 by 9 feet	11	—	22	.02	—	.07	.4	—	.6
12 by 12 feet	19	—	13	.27	—	.08	1.8	—	.7
15 by 15 feet	—	4	4	—	.02	.06	—	.2	.4
18 by 18 feet	—	6	—	—	.02	—	—	.1	—

[a] There was no mortality during the first period from 1973 to 1977.

Volume Growth and Yield

Gross annual volume increment was significantly ($P<0.01$) related to spacing in the same way as was basal area growth—greatest growth at narrow spacings and decreasing as spacing became wider (table 4). The highest annual increment measured was 81 cubic feet per acre for lodgepole pine during the third period; the lowest was 4.2 cubic feet per acre for the mixed species during the first period. For all spacings and species combinations, annual growth nearly doubled from period to period with an average of 14 cubic feet per acre the first period, 26 cubic feet the second, and 50 cubic feet the third.

Pure lodgepole pine had the greatest annual volume growth (32 cubic feet per acre), pure ponderosa pine had the least (27 cubic feet), and growth of the mixed species was intermediate (31 cubic feet) when averaged over all spacings and periods. These differences were not significant. Compared to ponderosa pine, lodgepole pine volume growth was greater at the 6-, 9-, and 12-foot spacings and less at the 15- and 18-foot spacings (table 4), but this spacing-species interaction was not significant.

Periodic gross annual volume increment was strongly related to stand density (basal area) (fig. 4). Curves for the pure ponderosa, pure lodgepole, and the mixed species were almost identical, and all data were combined for the last two growth periods. Volume increment showed a steady rise as stand density increased, and considerable volume growth was measured even at low stand densities. At a density of only 5 square feet of basal area per acre, volume growth was about 25 cubic feet per acre per year.

Table 4—Periodic annual gross basal area and total volume increment of a ponderosa pine, lodgepole pine, and mixed ponderosa pine-lodgepole pine plots during 3 measurement periods from 1973 to 1986

Age and spacing	Gross basal area growth[a]				Gross total volume growth[a]			
	Ponderosa	Lodgepole	Ponderosa-Lodgepole	Mean	Ponderosa	Lodgepole	Ponderosa-Lodgepole	Mean
	Square feet per acre[b]				*Cubic feet per acre*[b]			
				1973-77				
Age 6-11 years:								
6 by 6 feet	1.32 ± 0.01	2.75 ± 0.33	3.01 ± 1.01	2.36 ± 0.53	25.7 ± 0.9	39.3 ± 1.8	36.5 ± 8.9	33.8 ± 4.2
9 by 9 feet	1.17 ± .21	1.74 ± .12	1.59 ± .10	1.50 ± .17	15.0 ± 1.5	20.1 ± 1.0	20.2 ± .2	18.4 ± 1.7
12 by 12 feet	.36 ± .13	.71 ± .02	.48 ± .03	.52 ± .10	5.2 ± 1.2	9.5 ± .1	7.6 ± .2	7.4 ± 1.2
15 by 15 feet	.41 ± .03	.42 ± .02	.66 ± .03	.50 ± .08	5.2 ± .2	5.5 ± .1	6.8 ± .1	5.8 ± .5
18 by 18 feet	.50 ± .08	.45 ± .10	.38 ± .06	.44 ± .03	5.1 ± .6	4.8 ± .8	4.2 ± 0	4.7 ± .3
				1978-81				
Age 12-15 years:								
6 by 6 feet	5.32 ± .35	6.39 ± .95	6.16 ± 1.18	5.96 ± .33	35.9 ± 4.3	48.5 ± 11.0	49.9 ± 5.2	44.8 ± 4.5
9 by 9 feet	4.69 ± .28	4.69 ± .05	5.33 ± .17	4.90 ± .21	33.4 ± 2.7	37.9 ± 1.4	36.3 ± 3.3	35.9 ± 1.3
12 by 12 feet	1.94 ± .14	3.03 ± .56	2.50 ± .47	2.49 ± .31	14.4 ± .4	24.3 ± 4.4	17.8 ± 3.1	18.8 ± 2.9
15 by 15 feet	2.59 ± .16	2.26 ± .10	2.61 ± .21	2.48 ± .11	18.2 ± 1.1	16.9 ± .7	20.1 ± 2.9	18.4 ± .9
18 by 18 feet	2.12 ± .35	1.78 ± .36	1.91 ± .07	1.93 ± .10	15.2 ± 2.3	14.7 ± 3.0	14.7 ± .6	14.8 ± .2
				1982-86				
Age 16-20 years:								
6 by 6 feet	7.37 ± .88	6.90 ± .52	6.61 ± 2.53	6.96 ± .22	59.1 ± 10.1	81.3 ± 10.2	71.8 ± 31.5	70.7 ± 6.4
9 by 9 feet	6.69 ± .03	5.62 ± .03	6.43 ± .12	6.25 ± .32	63.3 ± .1	64.7 ± 3.0	70.5 ± 4.1	66.2 ± 2.2
12 by 12 feet	3.73 ± .90	4.16 ± .63	3.78 ± .66	3.88 ± .14	30.5 ± 5.8	48.5 ± 7.9	38.1 ± 8.5	39.0 ± 5.2
15 by 15 feet	4.49 ± .15	3.66 ± .06	3.95 ± .43	4.03 ± .24	48.5 ± 1.2	40.4 ± .2	42.8 ± 7.5	43.9 ± 2.4
18 by 18 feet	3.58 ± .54	2.50 ± .26	3.11 ± .13	3.06 ± .31	38.4 ± 6.0	30.0 ± 4.2	35.1 ± 1.5	34.5 ± 2.4

[a] Includes ingrowth; growth during first period (1973-77) is all ingrowth. During second period (1978-81) basal area ingrowth was 5 percent when averaged over all spacings and volume ingrowth was 11 percent. During third period (1982-86) both basal area and volume ingrowth were less than 1 percent.
[b] Mean ± standard error.

Twenty years after planting, the net volume yield of pure ponderosa pine and pure lodgepole pine at the five spacings reflect the pattern of growth during this time—less wood produced by ponderosa pine at the 6-, 9-, and 12-foot spacings and more wood produced at the 15- and 18-foot spacings when compared to lodgepole pine (fig. 5). The greatest difference between the two species was at the 12-foot spacing where the yield of ponderosa pine was 42 percent less than that of lodgepole pine. In contrast, the yield of ponderosa pine at the 18-foot spacing was 22 percent greater than that of lodgepole pine. Instead of the expected pattern of decreasing yield as spacing became wider as found for lodgepole pine (fig. 5), the yield of ponderosa pine at the 12-foot spacing was the lowest of any of the spacings. This greatly reduced yield of ponderosa pine at the 12-foot spacing is a result of slower diameter and height growth during the 20-year study period. The cause of this growth and yield reduction of ponderosa pine at the 12-foot spacing is not readily apparent, other than perhaps a greater incidence of the *Armillaria* root rot.

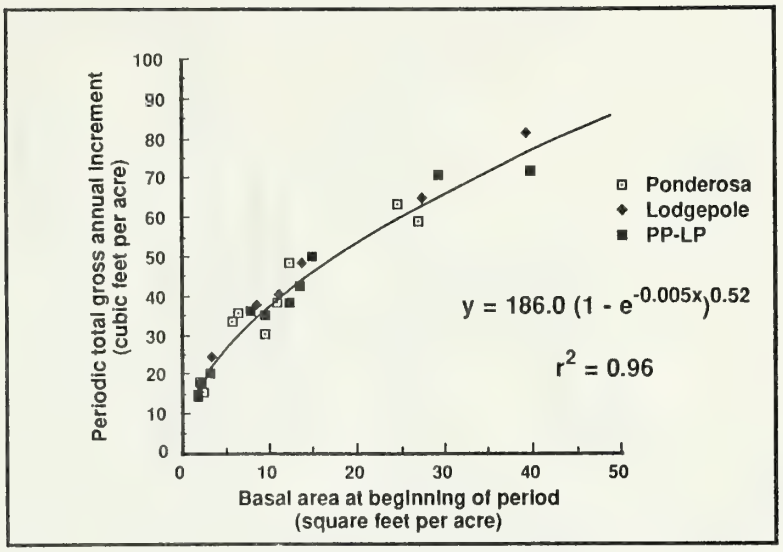

Figure 4—Periodic total gross annual cubic volume increment of ponderosa pine, lodgepole pine, and a mixture of both species as a function of basal area at the beginning of the last two growth periods.

Study results for volume yield after 20 years show a comparative advantage for lodgepole pine at the narrow spacings and an advantage for ponderosa pine at the wide spacings. Perhaps the narrower crowns and smaller branches of lodgepole pine allow this species to maintain better growth rates than ponderosa pine does in dense stands because of less crown shading.

Net yield of pure ponderosa, pure lodgepole, and the mixed species as a function of stand density (trees per acre) are given in figure 6. Besides the lower than expected yield of ponderosa pine at 302 trees per acre (12-foot spacing), yield was also reduced at 1,210 trees per acre (6-foot spacing) compared to lodgepole pine, which resulted in a relatively constant yield as tree numbers decreased from 1,210 to 538 per acre. The curves for lodgepole pine and mixed species showed a pattern of increasing yield with increasing number of trees per acre. Yield of the mixed species was generally intermediate between that of the pure ponderosa and pure lodgepole. The relatively constant yield of ponderosa pine at stand densities from 500 to 1,200 trees per acre differed from yields reported by Barrett (1982) who found increasing yields as tree numbers per acre increased. This stand density-yield relation for ponderosa pine should become clearer as more data from these spacing studies become available.

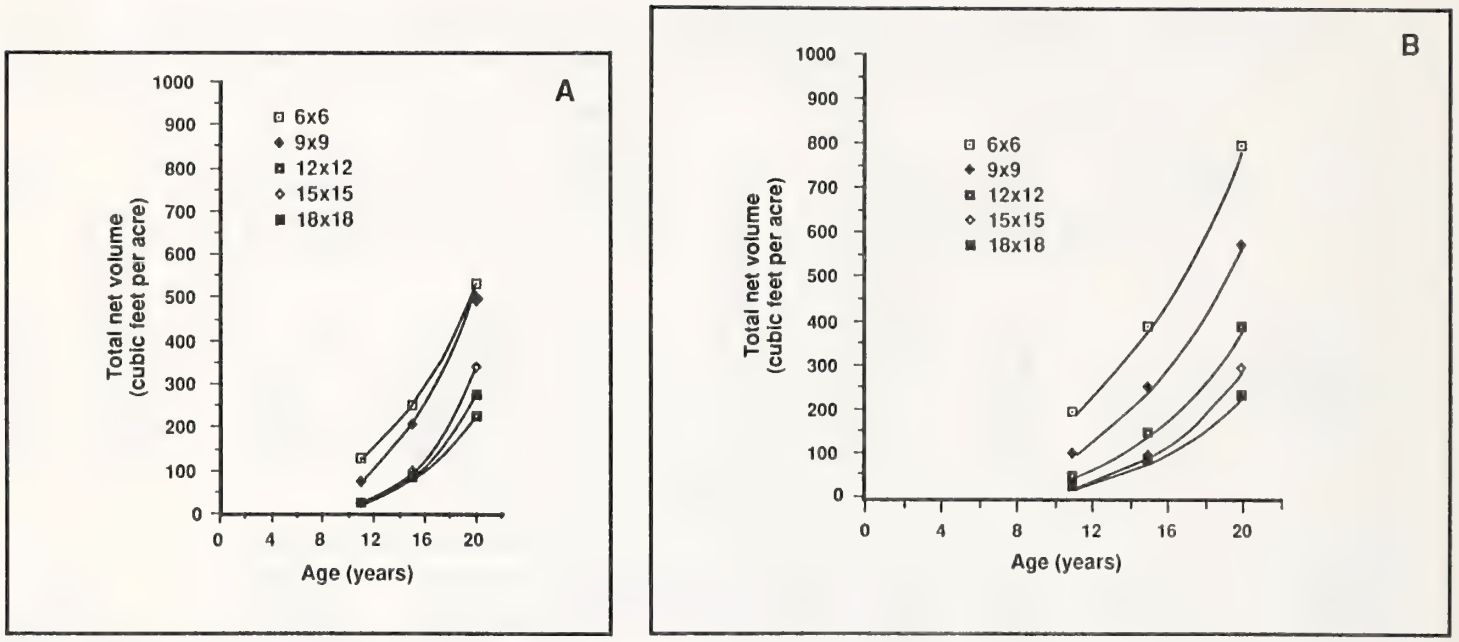

Figure 5—Total net cubic volume yield of trees growing at five initial spacings from age 11 to 20: **(A)** ponderosa pine and **(B)** lodgepole pine.

To produce trees of given sizes (d.b.h.) in less time, or conversely, to produce larger trees in the same time, stand density must be controlled to attain the diameter growth rate sufficient to reach the target diameter within the desired time frame. Because maximum volume yield generally occurs at high stand densities, and maximum diameter growth occurs at low densities, some yield is sacrificed to produce larger trees within a given time. In pure lodgepole pine, for example, average stand diameter increased from 3.4 inches to 4.4 inches after 20 years as the number of trees per acre decreased from 1,210 to 538. This also resulted in a volume yield reduction of about 28 percent.

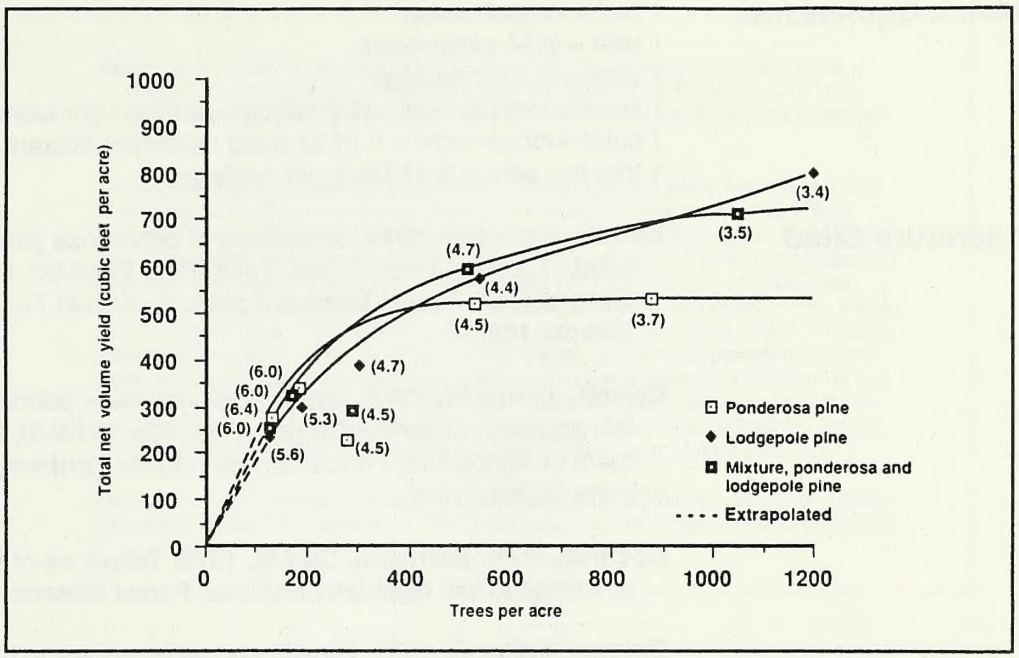

Figure 6—Total net cubic volume yield after 20 years for planted ponderosa pine, lodgepole pine, and a mixture of both species growing at five initial spacings. Average diameters (inches in d.b.h.) for each density are shown in parentheses.

Conclusions

Volume yield after 20 years in these planted stands was similar for the pure ponderosa, pure lodgepole, and mixed species except for the unexpected reduction in volume yield of pure ponderosa pine at the 6- and 12-foot spacings. The growth response to stand density followed the usual pattern of greater volume growth and less diameter growth as stand density increased (closer spacing).

Spacing studies provide information to land managers on tradeoffs between diameter growth rates and volume yields at various stand densities. A relatively wide spacing generally is desirable in young seedling and sapling-size stands to promote rapid diameter growth and thus shorten the time for trees to reach merchantability limits for lumber production. Wide spacings are also indicated if precommercial thinning is not a management option. It is important to select a plantation spacing that will not result in basal area levels that cause reduced tree vigor and predispose the stand to attacks from the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) before the first thinning can be made (Barrett 1979, Larsson and others 1983, Mitchell and others 1983).

Metric Equivalents

1 foot = 0.3048 meter
1 inch = 2.54 centimeters
1 acre = 0.4047 hectare
1 square foot per acre = 0.2296 square meter per hectare
1 cubic foot per acre = 0.0700 cubic meter per hectare
1 tree per acre = 2.47 trees per hectare

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The growth response after 20 years from an initial spacing study established in a ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) plantation was measured in central Oregon. The study was designed to compare the growth rates of pure ponderosa pine, pure lodgepole pine, and a 50-percent mixture of each species planted at 6-, 9-, 12-, 15-, and 18-foot spacings. Diameter growth of pure ponderosa pine was greater than that of pure lodgepole pine at all spacings, although pure lodgepole grew faster in height than pure ponderosa. Growth of the mixed-species stands was generally intermediate. Both basal area and total cubic volume increment per acre increased at the narrower spacings, but diameter growth per tree was less. Volume yield in these plantations after 20 years was similar for the pure pine and mixed species except for a reduction in yield of the ponderosa pine at the 6- and 12-foot spacings.

Keywords: Stand density, plantation spacing (-growth, increment, ponderosa pine, *Pinus ponderosa*, lodgepole pine, *Pinus contorta*, central Oregon, Oregon (central).

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